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Changes in the Pattern of Tooth Wear From Prehistoric to Recent Periods in Japan

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ABSTRACT Although a number of studies have been performed on interpopulational variation of tooth wear patterns in recent humans, the major interest in the study of tooth wear so far has been in reconstructing the subsistence and behavior of prehistoric populations, and hence research on wear pattern changes in historic times has been superficial. The present study investigated temporal change in the pattern of wear on the permanent dentition of the Japanese through comparison of the following five groups: prehistoric hunter-gatherers, prehistoric agriculturists, medieval, premodern, and recent populations.

The pattern of reduction of occlusal wear severity across these chronological groups was not similar between the anterior and posterior portions of the dentition. Occlusal wear on the anterior teeth was noticeably lighter in the prehistoric agriculturists and later populations than in the prehistoric hunter-gatherers, while clear reduction of occlusal wear on the posterior teeth occurred after medieval times. The temporal variations in the degree of mesiodistal crown diameter loss due to wear and its anterior-posterior gradient within the dentition are generally consistent with those observed in the occlusal wear pattern. Possible causative factors of these temporal changes in the wear pattern are discussed. Am J Phys Anthropol 109:485–499, 1999. © 1999 Wiley-Liss, Inc.

Anthropologists have so far investigated the relationship between the patterns of tooth wear and subsistence and/or behavior through comparisons of various modern human populations (e.g., Molnar, 1971, 1972; Smith, 1972; Walker, 1978; Hinton, 1982; Puech et al., 1983). Major results of these studies have been, e.g., documentation of a general reduction of wear accompanied by subsistence change from foraging to food-production (see Larsen, 1997 for a review and references), and documentation of worldwide differences between prehistoric hunter-gatherers and agriculturists in the angle of the occlusal wear plane on the molars (Smith, 1984).

So far, most studies on the pattern of tooth wear in modern humans have been archaeological, for the purpose of reconstructing the subsistence of prehistoric populations. Because of this, studies on changes in the wear pattern in historic times have been superficial. It is well-known that severity of wear was reduced after the Agricultural Revolution, accompanied by the development of technology and industry. Reduction of wear accompanied by shifts in diet from traditional tough foods to modern processed foods has been documented in transitional popula-

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TABLE 1. Materials used in this study

Sample name	Period	Estimated age of samples	Regions	N[1]				Collection[2]
				M	F	Juv.	Total	
Jomon	Jomon (prehistoric)	4,000–300 BC	Hokkaido, Honshu, and Kyushu	49	26	5	80	TUM, NSM
Yayoi	Yayoi (prehistoric)	300 BC–AD 300	Northern Kyushu and Yamaguchi	20	15	7	42	Kyushu University
Kamakura	Kamakura (medieval)	AD 1333	Kanto	55	35	8	98	TUM, NSM
Edo	Edo (premodern)	AD 1600–1868	Tokyo	46	29	6	81	NSM
Recent	Meiji-Taisho (recent)	AD 1868–1926	Unknown	36	12	2	50	TUM

[1] The number of sexed individuals (dental age ≥14 years) (columns M and F) and unsexed individuals (dental age <14 years) (in "Juv." column; Juv., juveniles).
[2] TUM, University Museum, University of Tokyo; NSM, National Science Museum, Tokyo.

tions of the twentieth century (e.g., Davies and Pedersen, 1955). However, details of changing wear patterns after the Agricultural Revolution until today are virtually unknown.

Furthermore, most previous studies focused on the rate and pattern of wear on the posterior teeth, and little effort has been made to document interpopulational differences in overall wear patterns. The dentition is a functional complex, and tooth wear should be discussed as a pattern over its entirety. In this context, the work of Hinton (1981) stands virtually alone as an attempt at systematic demonstration of differences in anterior vs. posterior wear accompanied by major subsistence change. He compared the wear patterns between hunter-gatherers (Eskimos and Australian Aborigines) and agriculturists (two groups of Amerinds) and showed that the former exhibit greater wear than the latter on the anterior teeth, both absolutely and relative to the posterior teeth. A similar trend had been also observed in Mexican Amerinds (Anderson, 1965), and Hinton (1981) emphasized that this may have been a universal difference between hunter-gatherers and agriculturists. Several studies, however, have indicated that variability in anterior vs. posterior wear pattern is present also within hunter-gatherers owing to differences in dietary resources, culinary practice, and environment (Richards, 1984; Molnar et al., 1989), and the suggestion made by Hinton (1981) should be confirmed in other populations, as he himself had noted.

This study examines temporal change in the pattern of wear on Japanese permanent dentitions from prehistoric to recent periods. The aspects investigated were the amount of loss of tooth substances in vertical and mesiodistal (MD) directions in individual teeth, and the anterior-posterior gradient of this loss within the dentition. Wear in the two different directions are dealt with separately. Occlusal wear is assessed both from its rate and its distribution of severity within a population. The MD loss of the crown is assessed by examining the degree of reduction of MD crown diameters with the advance of occlusal wear.

Temporal changes of tooth wear pattern in the Japanese have so far been studied by Inoue et al. (1982, 1984) and Hanihara et al. (1988). These studies, however, were problematic in several respects. In the former, the wear-scoring method was not appropriate, and interpopulation differences in age composition were not taken into consideration. The latter adopted the inappropriate analytical method of Scott (1979a) (cf. Richards, 1984; Benfer and Edwards, 1991). In addition, these studies did not sufficiently discuss selection criteria of the materials.

MATERIALS AND METHODS

Samples

The materials used in this study and other relevant information are presented in Table 1. Hereafter, the terms Jomon, Yayoi, Kamakura, Edo, and Recent are used in this paper to refer to samples from the Jomon to Recent periods.

The Jomon people were prehistoric hunter-gatherers, with one of the world's earliest pottery-making traditions (Imamura, 1996). They prepared and cooked foods with implements such as stone mortars and pestles,

and pottery. Within the Jomon population, variability was present in available food resources and ways of cooking, depending on the region, period, and environment (e.g., Sasaki, 1991). Nevertheless, materials from various regions in Japan were pooled in this study, since the available materials throughout Japan so far show only a limited degree of morphological variation in various parts of the skeleton (Baba and Etoh, 1989; Dodo, 1982, 1986; Mouri, 1988; Naito and Matsushita, 1977; Yamaguchi, 1981, 1982, 1989; Kaifu et al., 1998), including the mandible (Kaifu, 1995) and teeth (Matsumura, 1989). Moreover, tooth wear patterns were similar within the Jomon sample according to the author's preliminary observations. The major portion of the present materials came from shell-mounds of the Middle to Final Jomon periods (ca. 3,000–300 BC) along the coast of the Kanto district.

The present Yayoi sample is composed of populations from northern Kyushu and Yamaguchi Prefecture (western Japan). These rice agriculturist and metalworking people are considered to be immigrants from the Asian continent or their offspring (Nakahashi, 1993). Recent studies have shown that the later Mainland Japanese evolved through the mixture of this population and native Jomon people, possibly with greater influence from the former (see Kaifu, 1997 for details).

The entire Kamakura sample of this study was derived from the Zaimokuza site in the southern Kanto region, which is considered to have been a temporary mass burial for war dead from a battle in 1333 (Mikami, 1956). This sample is not regarded as that of a small local population but as including remains of soldiers and their servants gathered from other areas in the Kanto region (Mikami, 1956). During the Kamakura period, earthernware mortars and graters diffused among common people, and ways of cooking become more complicated (Koyama, 1994).

The Edo sample consists of remains from ordinary burials excavated in the city of Edo (present Tokyo). In Edo, food resources diversified following the development of transportation, and cooking techniques developed, too, as reflected by the publication of various cookery books and an increase in the number of restaurants (Koyama, 1994).

The Recent sample is comprised of specimens derived from dissecting rooms. Accompanied by an influx of Western foods, the variety of foods in the Meiji (1868–1912) and Taisho (1912–1926) periods became even greater than in the Edo period (Koyama, 1994).

Material selection

Antemortem tooth loss, significant breakage of the crown by caries, and tooth dislocation by periodontitis are major factors which disturb original normal wear patterns. Among specimens with their first molars fully erupted, those meeting the following criteria in the dentition anterior to the third molars were selected, supposing that the conditions of the third molars did not significantly affect the overall wear pattern: 1) no such abnormal tooth in either maxillary or mandibular arches (N = 264); 2) one or two such abnormal teeth exist, but their influence on overall wear pattern is negligible as evaluated from symmetry of wear between the right and left arches judged by the naked eye (N = 57); and 3) the mandible is missing but the maxillary dental arch is complete, and there is no sign of disordering factors in the missing mandible, as judged by continuity and symmetry of occlusal wear and absence of extraerupted teeth in the maxillary arch (N = 82). Extraeruption of a tooth occurs when it loses its antagonist(s) (Anneroth and Ericsson, 1967; Compagnon and Wada, 1991). As for the second and third categories, the number of specimens rejected owing to "abnormal" wear patterns were few, and the selected samples should not have been biased by this selection process. A specimen that showed an abnormal wear pattern probably due to bruxism (Edo), and several specimens with traces of dental treatment (Recent), were excluded.

The samples selected through the above process were somewhat male-biased in all chronological groups (Table 1). The reason for this is difficult to determine. Apart from the matter of preservation, the nature of the parent populations may explain part of this bias in the Kamakura and Edo samples. The former is composed of war dead and includes

a number of remains of soldiers and their servants, as already mentioned. It is also known from the historical records that the male population of the city of Edo was overwhelmingly larger than the female population.

Sex and age determination

Sex was determined by the present author mainly on the basis of pelvic and cranial morphology, for all specimens whose dental age was 14 years or more. Sex in the Recent sample is known from records. Dental age was judged for subadult specimens with reference to Ubelaker (1989, Fig. 71) to be from 7–20.5 years, with an interval of 0.5 years. The dental development sequence of the Japanese has not been sufficiently investigated so far, and the chart of Ubelaker (1989), compiled from data on Native Americans and other "non-American White" populations for the purpose of studies of Native Americans, is considered the best substitute. Ages of adult specimens were also estimated from ectocranial suture closure (see below).

Analyses

Occlusal wear. In this study, the first and second molars were used to represent occlusal wear on the posterior teeth, and the canine and central incisors were used to represent occlusal wear on the anterior teeth. These teeth were chosen in view of their relative positions in the arches and convenience in wear quantification.

Among the quantification methods of occlusal wear applicable to a cross-sectional study are qualitative ones which give a score following subjective criteria (e.g., Murphy, 1959; Molnar, 1971), and quantitative ones such as crown height (Tomenchuk and Mayhall, 1979; Kieser et al., 1985; Walker et al., 1991), ratio of area of exposed dentin to that of occlusal surface (Behrend, 1977; Walker, 1978; Richards, 1984; Richards and Miller, 1991), and ratio of worn area to that of occlusal surface (Molnar et al., 1983). Although the methods utilizing area have an advantage in accuracy, they can evaluate only a part of the entire wear process, depending on the subject to be measured. In the case of measuring area of exposed dentin, for example, the early stage of wear (when only the enamel is worn) is neglected. Therefore, in this study, the elaborate method proposed by Scott (1979b) was used for the molars (*M2* and *M1 wear score*). In this method, the occlusal surface is visually divided into four quadrants, and each is graded 1–10. The score for the whole tooth is the sum of these four numbers, and ranges from 4–40. Devising a proper quantification method is not easy for the canine and central incisor. Therefore, buccal crown height was used in the analyses of occlusal wear (*C* and *I1 crown height*). This method is intuitive and useful when interpopulational difference is great.

Principal component analyses (PCAs) were applied to the combined adolescent and adult subsamples of the five chronological samples, using the four occlusal wear parameters as variables. By this method, between-sample comparisons can be made for the distribution of wear severity and antero-posterior wear gradient. Differences in age distribution among these subsamples were examined beforehand by comparing ages estimated from dental development for the subadults and from ectocranial suture closure for the adults. The equation of Koizumi (1982), based on the model I quantification theory analysis for the same recent Japanese sample as in the present study, was utilized in the adult age estimation. The rate of wear was also assessed by bivariate analyses between wear severity and dental age for subadult subsamples.

MD loss of the crown. In order to assess the loss of the MD crown diameters due to wear, MD crown diameters from I1–M1 (average of the right and left sides) and their total sum (*total MD crown diameter*, *TMDCD*), the sum of I1–C (*anterior MD crown diameter*, *AMDCD*), and the sum of P3–M1 (*posterior MD crown diameter*, *PMDCD*) were contrasted with the advance of occlusal wear. The MD diameter of a tooth was measured only when both adjacent teeth were present in normal conditions. The sec-

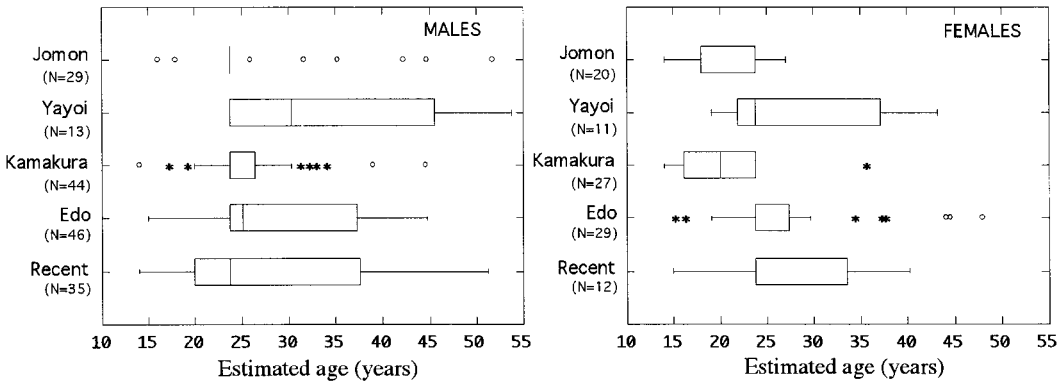

Fig. 1. Box plots of estimated ages for subsamples with estimated ages of 14 or more. Age estimation was based on dental development for subadults, and ectocranial suture closure for adults. Maximum estimated age for subadults is 20.5 years, and minimum estimated age for adults is 23.7 years. The vertical line inside a box indicates median. Left and right sides of a box indicate 25% and 75% quartiles and are called lower and upper hinges, respectively. The transverse length of a box (interquartile range) is called Hspread. "Inner fences" are points located at a distance of 1.5 Hspread from the lower or upper hinges. "Outer fences" are points located at a distance of 3 Hspread from the lower or upper hinges. Lines extending from a box indicate range of scores located inside the two inner fences. Values outside the inner fences are plotted with asterisks, and those outside the outer fences with open circles. The 25% and/or 75% quartile(s) and median overlap at age 23.7 years in the Jomon male and female, Kamakura male, Edo female, and Recent female samples.

ond molar was excluded from this analysis because the presence or absence of the distal interproximal wear on this tooth is affected by the condition of the third molar. For the occlusal wear parameter on the anterior teeth in this analysis, labiolingual diameter of the dentin exposed on the occlusal surface of the central incisor (*I1 dentin thickness*) was used instead of crown height. This is because a wear parameter that has correlation with MD crown diameter is not suitable for this analysis. *I1 dentin thickness* was measured in the projected plane perpendicular to the long axis of the crown, and not in the occlusal plane.

The mean of right and left sides was used for the analyses, but one side was used when data on the other side were not available. Linear measurements were performed to the nearest 0.1 mm. All statistical procedures were performed using SYSTAT Macintosh 5.2.1 (SYSTAT, Inc, 1992).

RESULTS

Age distribution

Distributions of estimated age for each sample are given in Figure 1. The Jomon and Kamakura adults inclined toward younger ages, while individuals of various ages were present in the other adult subsamples in both sexes. Two-tailed Mann-Whitney U tests showed that the differences in the estimated age compositions of the adult subsamples between the Jomon and Kamakura, and the others, were significant at the 5% level in every pair except one in which the probability was 0.08, while probabilities for all other pairs were more than 0.26.

The actual ages of most Recent specimens are known from the records, the median of the adult subsample being 29.5 years for the males (N = 20, maximum of 51 years), and 26.0 years for the females (N = 9, maximum of 48), indicating that the distributions of the actual and estimated ages of the adults are not very different in this sample. The correlation coefficient between the actual and estimated ages for the Recent adults was 0.47.

Principal component analysis

The principal component analysis (PCA) was performed using *M2* and *M1 wear score*, and *C* and *I1 crown height* as variables. Materials analyzed were those specimens whose sex was determinable (dental age ≥14 years). The matrix used was the correla-

TABLE 2. Rotated factor loadings[1]

Variables	Males						Females					
	Maxillae			Mandibles			Maxillae			Mandibles		
	F I	F II[2]	F III	F I	F II[2]	F III	F I	F II[2]	F III	F I	F II[2]	F III
M2 wear score	0.85	0.41	−0.18	0.87	0.39	−0.18	0.84	0.36	−0.32	0.82	0.44	−0.24
M1 wear score	0.91	0.34	−0.22	0.91	0.36	−0.18	0.90	0.33	−0.27	0.87	0.39	−0.27
C crown height	−0.41	−0.72	0.57	−0.42	−0.74	0.53	−0.39	−0.85	0.37	−0.46	−0.66	0.58
I1 crown height	−0.38	−0.91	0.16	−0.37	−0.92	0.12	−0.41	−0.55	0.73	−0.43	−0.87	0.23
Total contribution (%)	46.5	40.6	10.7	47.5	41.8	8.9	45.6	31.2	21.3	45.8	38.8	13.1
Cumulative proportion (%)	46.5	87.1	97.8	47.5	89.3	98.2	45.6	76.9	98.0	45.8	84.6	97.7

[1] F, factor.
[2] Plus and minus signs were reversed for convenience.

tion matrix (computed by the pairwise deletion method) of the pooled Jomon to Recent sample. The first components were rotated using the Varimax method to achieve more meaningful factor loadings; the results are shown in Table 2. In both jaws and sexes, the first factor (factor I) gives greater scores if wear on the posterior teeth is heavy, and the second factor (factor II) gives greater scores if wear on the anterior teeth is heavy. The two factors explain about 80% of the total variance in every case. The factor scores for each individual are shown in Figure 2, and the average scores for each sample are tabulated in Table 3.

In factor I of both jaws, the Jomon and Yayoi show a great range of variation from heavy to light wear, while most of the Edo and Recent specimens show light wear in both sexes. The Kamakura males show an intermediate tendency between them, while the wear score distribution of the females is similar to that of the Jomon and Yayoi. In factor II of both jaws, the Jomon again show a great range of variation, while specimens with light wear are dominant in the others in general. Yayoi wear is slightly heavier than the Kamakura, Edo, and Recent in a comparison of the average scores of factor II.

Regression analysis

Table 4 shows the regression coefficients of the wear scores on dental ages for the subadult subsamples for which dental age can be assessed. Although dental ages are subject to error relative to actual ages, regression is used because the purpose here is to predict wear severity as a dependent variable from age as an independent variable. As for the Recent sample, adult specimens with known actual age were also included, and the regression equations were calculated for two cases (subadults and all specimens). Both sexes were mixed here because sex determination is difficult for an individual before adolescence. The wear score for a molar immediately after eruption is 4 in the system of Scott (1976b). In the standard adopted in this study (Ubelaker, 1989), dental age for an individual with just-completed eruption of the second molar is about 13, and that for the first molar is 7. Thus, the regression equations in Table 4 are controlled to path (13, 4) for the second molar, and (7, 4) for the first molar. The equations for the anterior teeth are ordinal, because average initial crown height for the parent populations cannot be accurately inferred for the anterior teeth owing to the small sample sizes. In addition to the small sample sizes, it should be noted in interpreting these results that the dental ages are subject to error relative to the actual ages, and the intervals of wear scores are not necessarily constant in the system of Scott (1979b). Scatterplots for selected variables are shown in Figure 3.

In the molars, the Jomon, Yayoi, and Kamakura samples show an apparently higher rate of wear compared to the Edo and Recent samples in both jaws and sexes. The regression coefficients of the Recent are lower in the entire sample than in the subadult subsample. This difference is probably an artifact of the scoring method adopted here, and cannot be interpreted as evidence for the existence of differences in wear rate depending on age. In the system of Scott (1979b), the change from 12 to 16 (from rounded to flat cusps) is expected to occur more slowly compared to that from 4 to 12

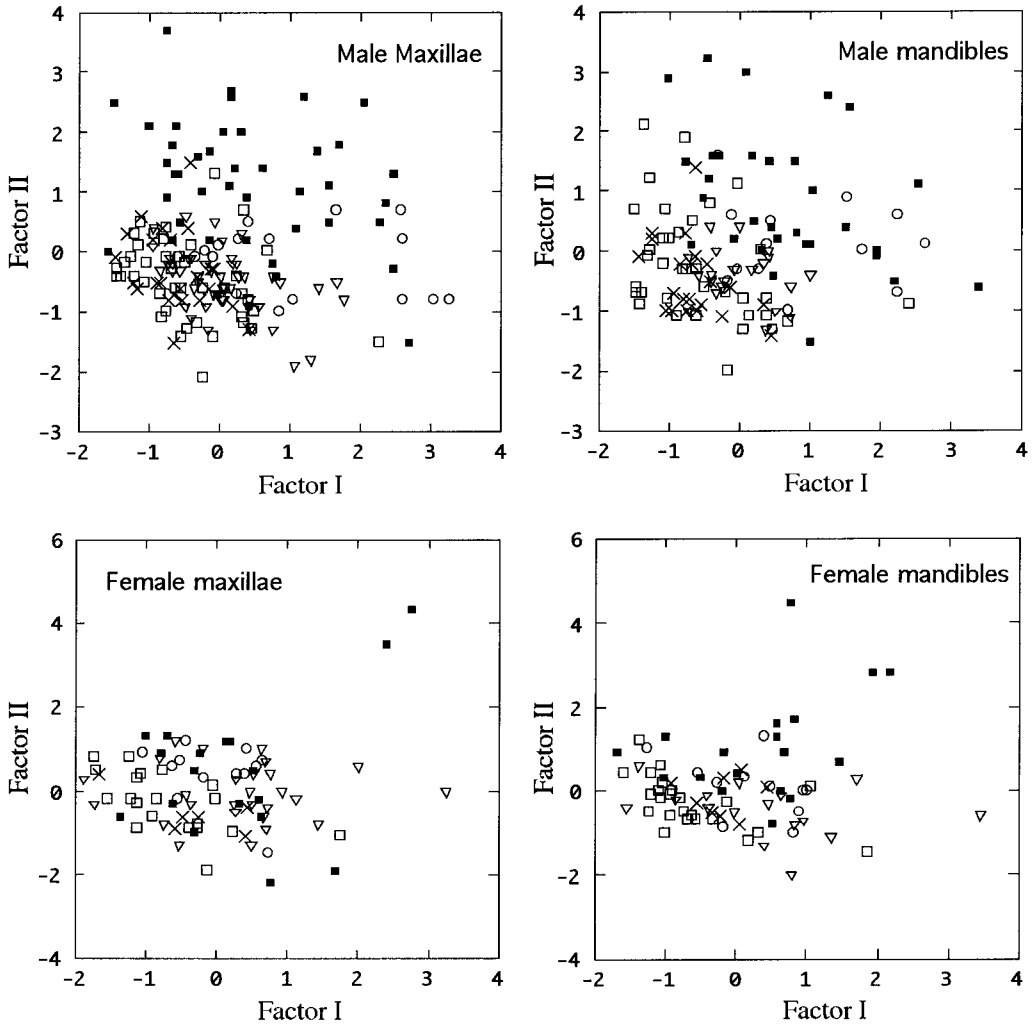

Fig. 2. Scatterplots of first and second factor scores. Solid squares, Jomon; open circles, Yayoi; open triangles, Kamakura; open squares, Edo; x, Recent.

TABLE 3. Mean factor scores[1]

	Males						Females					
	Maxillae			Mandibles			Maxillae			Mandibles		
	N	F I	F II	N	F I	F II	N	F I	F II	N	F I	F II
Jomon	42	0.42	−1.12	31	0.64	−0.86	18	0.26	−0.47	18	0.35	−1.08
Yayoi	17	1.07	0.15	14	0.83	−0.09	14	0.05	−0.44	11	0.23	−0.08
Kamakura	47	0.08	0.49	21	0.01	0.42	27	0.31	0.05	16	0.37	0.47
Edo	42	−0.43	0.48	36	−0.55	0.25	20	−0.67	0.30	24	−0.63	0.29
Recent	24	−0.61	0.31	22	−0.65	0.47	6	−0.36	0.51	8	−0.21	0.12

[1] F, factor.

(from minimum wear to the cusps being rounded). The coefficients for the anterior teeth are negative in most cases because the crown heights were used as wear parameters. Both the canine and central incisor show a high rate of wear in the Jomon and Yayoi, while those of the Kamakura, Edo, and Recent samples are small and near zero.

TABLE 4. Regression coefficients for subadult subsamples (mixed sex)[1]

	M2 wear score			M1 wear score			C crown height					I1 crown height				
	N	b	SE of b	N	b	SE of b	N	r^2	b	a	SE of b	N	r^2	b	a	SE of b
Maxillae																
Jomon	10	1.48	0.24	15	0.97	0.10	13	0.20	−0.19	13.15	0.11	14	0.21	−0.13	12.75	0.07
Yayoi	3	1.35	0.25	9	0.84	0.13	6	0.81	−0.23	13.21	0.06	10	0.66	−0.19	13.89	0.05
Kamakura	17	0.99	0.15	27	0.82	0.05	24	0.06	−0.06	11.40	0.05	23	0.01	0.01	11.12	0.04
Edo	16	0.64	0.10	19	0.49	0.05	15	0.01	0.04	10.66	0.10	16	0.01	0.03	11.88	0.07
Recent (subadults)	11	0.74	0.10	13	0.52	0.06	10	0.00	−0.01	11.33	0.13	12	0.00	0.01	11.66	0.08
Recent (all specimens)	39	0.34	0.03	41	0.31	0.02	32	0.25	−0.05	11.88	0.02	31	0.06	−0.03	12.09	0.02
Mandibles																
Jomon	9	1.06	0.40	12	0.93	0.10	12	0.59	−0.31	14.63	0.08	13	0.34	−0.15	10.35	0.06
Yayoi	4	1.57	0.22	9	0.82	0.11	6	0.78	−0.26	14.10	0.07	9	0.33	−0.11	10.40	0.06
Kamakura	10	1.19	0.09	13	0.78	0.06	11	0.13	−0.11	11.71	0.09	13	0.01	−0.01	8.96	0.05
Edo	16	0.51	0.09	19	0.47	0.06	18	0.00	0.02	11.41	0.09	11	0.08	−0.05	10.17	0.06
Recent (subadults)	10	0.78	0.10	11	0.56	0.08	9	0.03	−0.05	13.08	0.12	13	0.09	−0.07	10.28	0.06
Recent (all specimens)	35	0.36	0.03	35	0.36	0.02	33	0.16	−0.05	12.30	0.02	30	0.06	−0.02	9.53	0.02

[1] The regression equation is: (wear parameter) = b*(age) + a. SE, standard error.

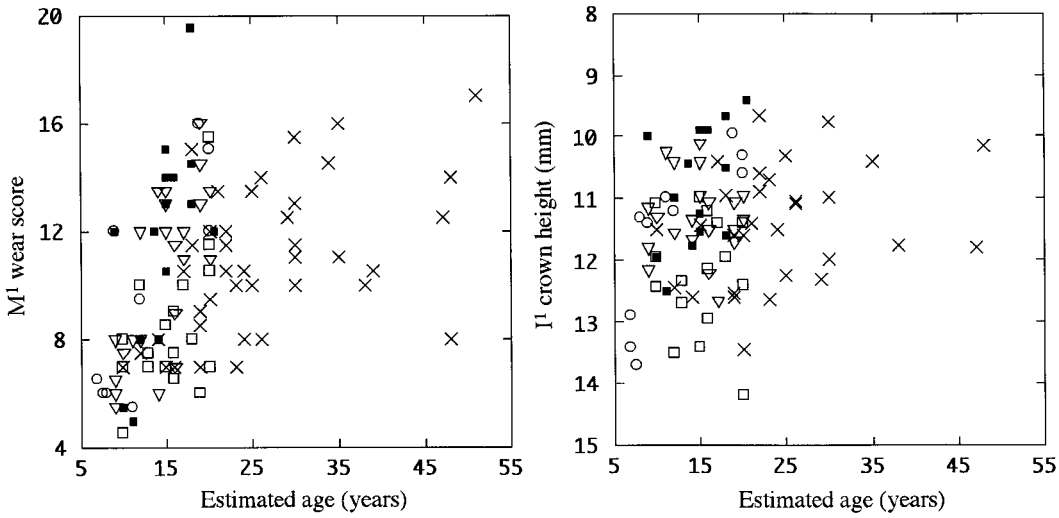

Fig. 3. Scatterplots of age and occlusal wear parameters (mixed sex). Dental ages are given for all subadult specimens, and actual ages are given for adults of the Recent sample. Symbols as in Figure 2.

Loss of MD crown diameters

Covariation between the advance of occlusal wear and change in the MD crown diameter was examined within each population. *Combined wear score* was defined as the parameter of occlusal wear on the dental arch as a whole. This is the standardized first-component score of the PCAs performed within each sex and jaw subsample of each population, using *M2* and *M1 wear score*, and *I1 dentin thickness* as variables (a greater value indicates heavier wear). Figure 4 gives the scatterplots of the *TMDCD* and *combined wear score* (dental age ≥14 years). Regression lines of the former on the latter are drawn onto these plots for reference. For a test of significance, each subsample was divided into two wear groups, using the median of the *combined wear score* (zero) as the boundary, and the one-tailed Mann-Whitney U test was conducted for *TMDCD*, *AMDCD*, and *PMDCD* between these groups of each subsample (Table 5).

From the above analyses, reduction of the *TMDCD* is apparent in both jaws of Jomon males, Yayoi males, and Edo males, in both

jaws of Jomon females, in the mandible of Yayoi females, and in the maxilla of Kamakura females. The average differences in *TMDCD* between the initial and final stages of occlusal wear are identifiable from Figure 3 as about 10 mm in both sexes and jaws of the Jomon, and about 3 mm in both jaws of Yayoi males, the mandible of Yayoi females, and both jaws of Edo males. The loss in Kamakura females is even smaller. In both sexes of the Jomon and in the Yayoi males, reductions of MD crown diameters were detected in either the anterior or the posterior segment of the dentition (Table 5), while in the other groups, the loss was relatively more apparent in the posterior teeth than in the anterior teeth in most cases.

The above results were further confirmed by the PCAs explained below. PCAs were performed for each subsample, using MD diameters of individual teeth, *M1 wear score*, and *I1 dentin thickness* as variables (dental age $\geq$14 years). The matrix used was the correlation matrix computed by the pairwise deletion method. The first-component loadings are shown in Table 6. While all of these loadings have high correlations with the MD diameters of each tooth (Recent females are an exception, probably owing to the small sample size), the loadings of the groups mentioned above generally also have high correlations with the occlusal wear parameters.

DISCUSSION AND CONCLUSIONS

The analyses of the ages estimated from ectocranial suture closure suggested the existence of a bias toward younger individuals in the age compositions of the Jomon and Kamakura samples. Although the data of ectocranial suture closure alone are not sufficient to demonstrate actual bias in age composition, these tendencies were observed in both sexes and are consistent with some expectations derived from the nature of their parent populations. The skeletal series from the Zaimokuza site, which composes the entire Kamakura sample of this study, is considered to have been a mass burial for war dead (Mikami, 1956), and the majority of the remains were reported to be those of young adult males (Suzuki, 1956). Whereas the Jomon, Yayoi, and Edo samples are from ordinary burials where individuals of various age groups from adolescents to the elderly were buried, it has been shown that the life expectancy of the Jomon people was very short (Kobayashi, 1967).

In general, the results of principal component and regression analyses were consistent. As for the molars, the Jomon, Yayoi, and Kamakura showed obviously heavier wear than the Edo and Recent. Among the former three samples, the similarity in wear score distribution between the Jomon and Yayoi is interpreted as indicating heavier wear in the former, taking the differences in age distribution into consideration. The observation that regression coefficients for the subadult subsamples were slightly higher in the Jomon than in the Yayoi is consistent with this view. On the other hand, because the Kamakura sample is biased toward young adults, a slightly lower distribution of the wear scores in the Kamakura males as compared to the Yayoi sample cannot be concluded as reflecting differences in wear severity between them. The regression analyses for the subadult subsamples suggested that wear rate in the Kamakura was almost equal to, or perhaps only slightly less than in the Yayoi.

Although the wear rate on anterior teeth was similar between the Jomon and Yayoi, the Yayoi showed an apparently lighter tendency in the wear score distribution in spite of the differences in age distribution between them. This indicates that wear on the anterior teeth was lighter in the Yayoi people than in the Jomon people. The high regression coefficients in the Yayoi sample may be artifacts of the small sample size, but it is also possible that the wear rate on the anterior teeth of these prehistoric agriculturists was higher in the growth period than in adulthood.

The patterns of tooth wear detected from this study can be summarized as follows. Description of the actual extent of wear severity in each sample is also included in these summaries.

Jomon people

Occlusal wear is very heavy over the entire arch in both jaws. In the advanced stage of wear, the tooth crowns may be

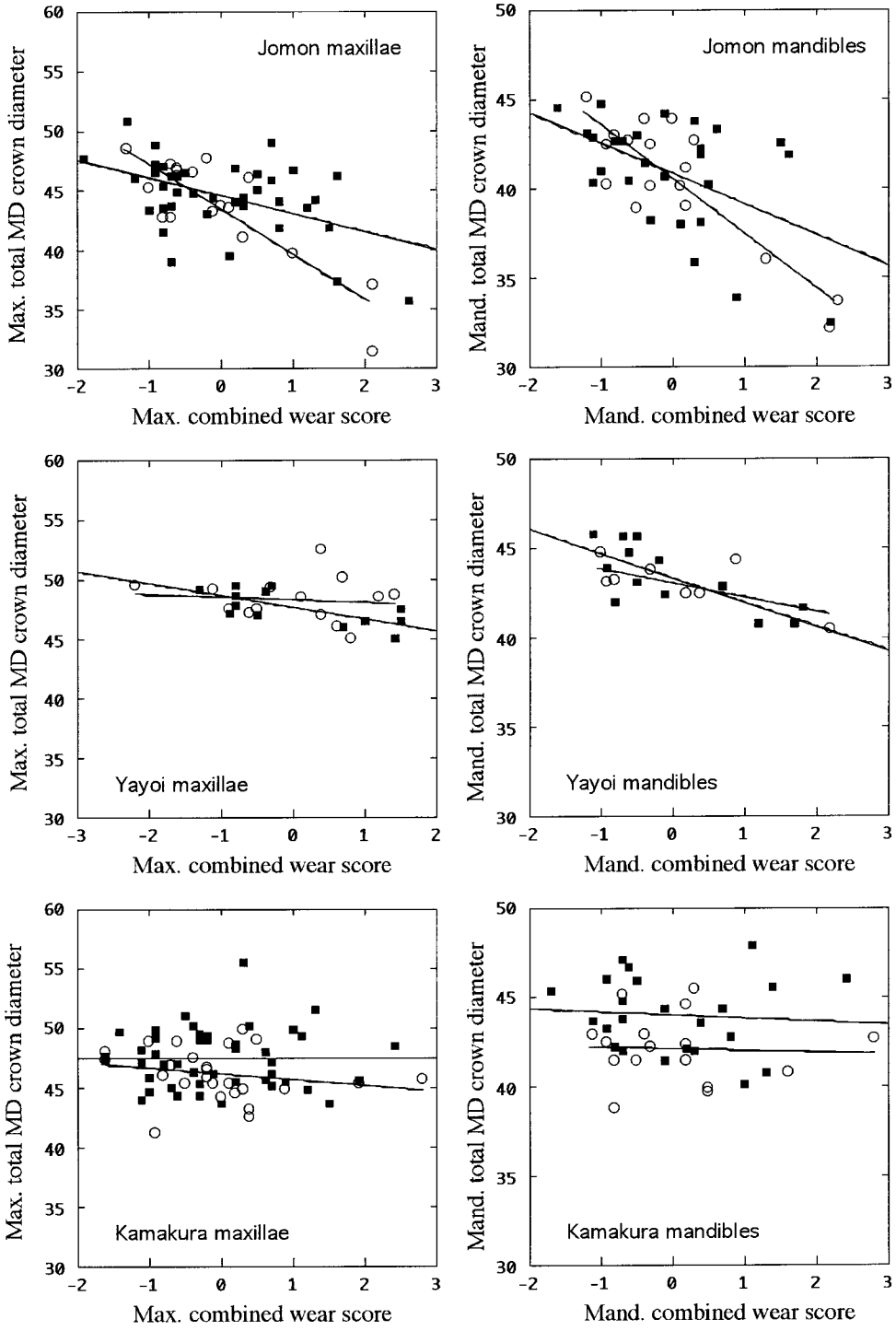

Fig. 4. Scatterplots and regression lines of the *combined wear score* and *total MD crown diameter*. Solid squares and longer line, males; open circles and shorter line, females. Max., maxillary; Mand., mandibular.

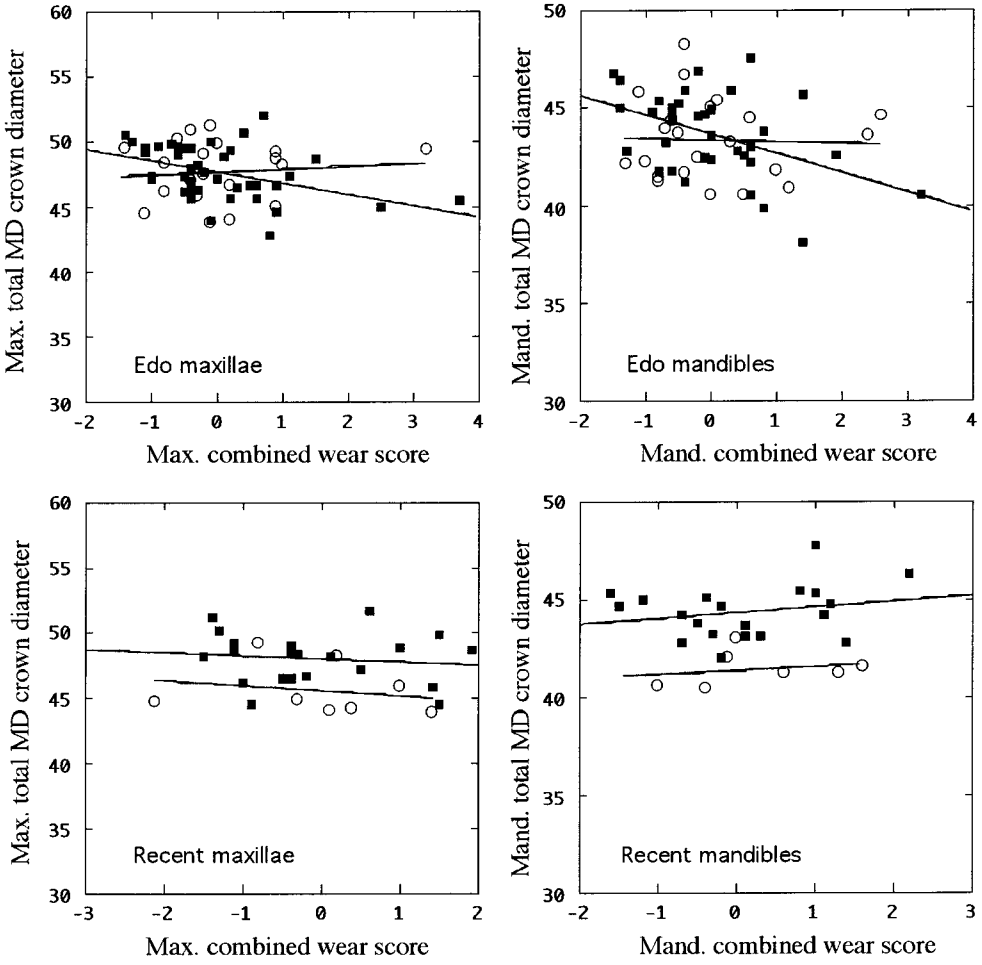

Fig. 4. Continued.

completely worn away, especially in the mandibular teeth. The amount of loss of MD crown diameters due to wear is also great in both the anterior and posterior segment of the dentition.

Yayoi people

Wear on the posterior teeth is heavy but slightly less than in the Jomon. Wear on the anterior teeth is noticeably lighter than in the Jomon but still heavier than in later Japanese populations. A certain degree of loss of MD crown diameters due to wear occurs in both jaws of males and in the mandibles of females. In the females, this loss is apparent only in the posterior teeth.

Kamakura people

Severity of wear on the posterior teeth is perhaps equal to or only slightly less than in the Yayoi, whereas wear on the anterior teeth is very light. The loss of MD crown diameters due to wear is nearly negligible and if seen at all, tends to be greater in the posterior than in the anterior teeth.

Edo people

Wear on the posterior teeth is clearly lighter than in earlier Japanese populations, although it reaches the level of complete obliteration of the cuspal morphology on the occlusal surface in the advanced stage. Wear on the anterior teeth is very

TABLE 5. Results of one-tailed Mann-Whitney U test for MD crown diameters

	Males				Females			
	Max.		Mand.		Max.		Mand.	
	N	*P*	N	*P*	N	*P*	N	*P*
Jomon								
TMDCD	40	0.07	26	0.03	18	0.01	17	0.05
AMDCD	40	0.03	26	0.03	18	0.01	17	0.03
PMDCD	41	0.09	28	0.04	19	0.01	18	0.03
Yayoi								
TMDCD	13	0.01	13	0.01	14	0.35	9	0.07
AMDCD	13	0.02	13	0.02	14	0.48	9	0.17
PMDCD	13	0.01	13	0.01	14	0.26	10	0.06
Kamakura								
TMDCD	45	0.39	23	0.18	26	0.05	16	0.34
AMDCD	46	0.57	23	0.30	26	0.18	16	0.40
PMDCD	45	0.23	23	0.16	28	0.02	16	0.44
Edo								
TMDCD	40	0.03	35	0.03	20	0.41	22	0.28
AMDCD	40	0.10	35	0.03	20	0.44	23	0.47
PMDCD	41	0.03	35	0.04	21	0.56	22	0.28
Recent								
TMDCD	22	0.52	20	0.75	8	0.15	7	0.86
AMDCD	23	0.51	20	0.69	8	0.56	7	0.98
PMDCD	24	0.63	23	0.36	8	0.15	9	0.31

light. Loss of MD crown diameters occurs in males to an almost similar extent to that observed in Yayoi males. The amount of the loss in females is negligible.

Recent people

The rate and pattern of occlusal wear are similar to those observed in the Edo people. The loss of MD crown diameters due to wear is negligible and if seen at all, tends to be rather greater in the posterior than in the anterior teeth.

The above results indicate that the pattern of temporal change of wear severity in the Japanese is not similar between the anterior and posterior teeth. This indicates that factors causing reduction of wear were different between the two regions of the dentition. This difference is to be expected when looking at the different roles played by the anterior and posterior teeth in food consumption, that of the former being initial preparation of food, and that of the latter being reduction of food.

The change in the posterior teeth probably relates strongly to changes in masticatory activity through time. This study revealed that the wear severity on the posterior teeth was noticeably reduced from that in the Edo period. A similar pattern of change was also observed in the mandible. The mandibles from almost the same samples as those in this study showed marked reduction (overall narrowing and reduction in the regions of major masticatory muscle attachments) from the Edo period onward (Kaifu, 1997). This mandibular reduction was interpreted, for several reasons, as caused mainly by underdevelopment of the jaw bone due to reduction of masticatory activities.

The principal factors which caused such reduction of masticatory activity might have been changes in food and culinary practice. Although accurate reconstruction of diets consumed by the populations examined here is difficult, there is some evidence for general reduction of toughness or consistency of food through time in Japan. Staple foods of the Japanese from the Yayoi period were mainly rice and other grains, but there were temporal variations in the varieties and ways of cooking (Koyama and Goshima, 1985; Tsukuba, 1994; Sasaki, 1991; Seguchi, 1998). Saitou (1987) confirmed experimentally that consistency of these staple foods generally decreased from the Yayoi period to modern times. Moreover, he reconstructed diets of the earlier Japanese aristocrats from the Yayoi to Edo periods and fed these to students, and found that the number of masticatory cycles and chewing time spent decreased with the recency of the simulated diets.

The difference in the anterior vs. posterior wear pattern detected between the Jomon and Yayoi in this study is consistent with previous observations between other hunter-gatherer and agricultural populations (Hinton, 1981; Anderson, 1965), in that hunter-gatherers show heavier wear on the anterior teeth, both absolutely and relatively. This strongly suggests that this was the universal pattern of change that accompanied the Agricultural Revolution. Factors affecting this change are rather difficult to discuss, and the present study did not provide sufficient data in this respect. Hinton (1981) emphasized the habitual nonmasticatory utilization of the anterior teeth as a primary cause in forming this distinctive wear pattern of hunter-gatherers. Such a possibility may be tested through examination of corre-

TABLE 6. Component loadings for the first principal components

Variables	Males					Females				
	Jomon	Yayoi	Kama.	Edo	Recent	Jomon	Yayoi	Kama.	Edo	Recent
Maxillae										
M^1 wear score	−0.52	−0.62	0.18	−0.58	−0.23	−0.89	−0.30	−0.38	0.01	0.05
I^1 dentin thickness	−0.70	−0.72	−0.22	−0.55	−0.10	−0.87	0.18	−0.41	0.11	−0.12
M^1 MD diameter	0.78	0.48	0.76	0.82	0.72	0.91	0.68	0.83	0.64	0.78
P^4 MD diameter	0.73	0.83	0.83	0.70	0.81	0.77	0.79	0.81	0.85	0.81
P^3 MD diameter	0.82	0.70	0.91	0.76	0.73	0.93	0.79	0.82	0.83	0.84
C^1 MD diameter	0.79	0.48	0.82	0.71	0.53	0.87	0.48	0.87	0.62	0.65
I^2 MD diameter	0.78	0.73	0.78	0.68	0.51	0.93	0.81	0.76	0.84	0.65
I^1 MD diameter	0.88	0.70	0.82	0.70	0.73	0.89	0.81	0.69	0.90	0.46
Total contribution (%)	56.9	44.4	51.4	47.9	35.4	78.3	42.2	51.8	46.7	37.9
N of pairs (min.–max.)[1]	40–46	14–20	46–54	42–48	24–33	20–24	14–15	28–35	21–29	8–12
Mandibles										
M_1 wear score	−0.27	−0.78	0.22	−0.41	0.18	−0.91	−0.81	−0.11	−0.13	−0.41
I_1 dentin thickness	−0.85	−0.85	0.26	−0.67	0.08	−0.91	−0.81	0.05	−0.02	−0.25
M_1 MD diameter	0.72	0.54	0.59	0.69	0.63	0.78	0.72	0.77	0.79	0.71
P_4 MD diameter	0.69	0.47	0.79	0.81	0.68	0.87	0.10	0.65	0.75	0.93
P_3 MD diameter	0.86	0.88	0.91	0.77	0.72	0.91	0.09	0.72	0.84	0.82
C_1 MD diameter	0.92	0.53	0.89	0.82	0.62	0.88	0.31	0.84	0.75	0.91
I_2 MD diameter	0.91	0.82	0.88	0.86	0.84	0.96	0.44	0.93	0.84	0.23
I_1 MD diameter	0.93	0.85	0.78	0.88	0.63	0.92	0.95	0.88	0.79	−0.17
Total contribution (%)	63.2	54.0	51.1	56.6	36.4	79.9	38.3	48.8	7.6	39.9
N of pairs (min.–max.)[1]	28–38	14–17	23–29	36–48	23–32	17–23	10–12	16–17	23–29	8–11

[1] The minimum and maximum (min.–max.) number of pairs of specimens used for calculation of the correlation matrix computed by the pairwise deletion method.

lation between sex and age differences in the frequency of nonmasticatory utilization of the anterior teeth and corresponding differences in the wear pattern.

Occlusal wear on the anterior teeth becomes even lighter from the Kamakura period. Among various possibilities, one factor which might have been significant for this change is the adoption and diffusion of chopsticks. The Yayoi people probably ate with their hands, as described in the *Wei zhi*, a 3rd century AD Chinese dynastic history (Sahara, 1996). Chopsticks were invented originally in China and imported to Japan sometime between the 3rd–7th centuries AD. They were used as implements in rites and rituals at first, and diffused among the common people, together with Buddhism, during the 8th–9th centuries AD (Honda, 1978; Ishiki, 1993). The role of the anterior teeth in initial food preparation must have been reduced by the adoption of chopsticks, which carry food directly into the inner part of the oral cavity.

The pattern of changes in MD crown diameter loss due to wear is generally consistent with changes in the occlusal wear pattern. The amount of this loss is greater in populations suffering severer occlusal wear. Although the Yayoi and Edo samples showed apparent sexual differences in the degree of MD crown diameter loss, that of the males being greater than the females, these are also consistent with sexual differences in the occlusal wear severity displayed in these populations (Kaifu, 1998). In addition, loss of MD diameters in the anterior teeth becomes comparatively less, in general, than that in the posterior teeth, with reduction of occlusal wear severity on the anterior teeth, which preceded that on the posterior teeth. Although the Yayoi males showed statistically significant reduction of MD diameters in anterior teeth, that reduction may also be relatively less compared to that in the posterior teeth. This possibility, however, cannot be securely confirmed with the available sample size.

One curious observation concerning MD crown diameter loss due to wear is that, while occlusal wear is heavier in the Kamakura than in the Edo samples, the males of the latter experienced a greater amount of loss of MD crown diameters with wear than the males of the former. This is probably due to a difference in incidence of interproximal spaces in the dentition between the two populations. In a comparison between them, the Kamakura showed a higher incidence of interproximal spaces in the anterior part of

the dentition than in the Edo (Kaifu, submitted).

Finally, this study has an important implication for research on tooth wear in humans. In studies of covariation between the change of a certain orofacial morphology such as facial height and the advance of tooth wear, the degree of occlusal wear in an individual has often been represented by that of the posterior teeth (e.g., Murphy, 1958, 1959, 1964; Fishman, 1976; Hylander, 1977). However, variation of wear on the anterior teeth must also affect orofacial morphology, especially the facial height or dental arch dimensions. As indicated in this study, there may be interpopulation variation in the balance of wear between the anterior and posterior teeth. Thus, wear parameters should be chosen after examination of the wear pattern on the dentition as a whole, based on the purpose and design of the study.

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